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HRL REPORT NO. R-3085

A CHART FOR COMPUTING RADAR MINIMUM JAMMING RANGE FOR SHIPS



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Washington, D.C.

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N R L REPORT NO. E-3086

**A CHART FOR COMPUTING RADAR
MINIMUM JAMMING RANGE FOR SHIPS**

by

W. S. Alderson

June 1947

Problem No. S411.IR-S

Approved by:

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ABSTRACT

This report describes a method of using a chart to determine the minimum range from a radar at which an echo from a ship can be screened by jamming. Two types of problems can be solved: (1) the problem of determining the minimum self-screening range for a ship, i.e., the minimum range to which a ship carrying a jammer can approach undetected; and (2) the problem of determining the minimum range of safe approach when the jammer is at a temporarily fixed location, not on the ship to be protected. Two problems are worked out to show the proper use of the chart.

REFERENCES

- 1) W. S. Alderson, "Radar-Simulation of Naval Surface Targets by Towed-Balloon-Borne Reflectors", NRL Report R-2522, 18 July 1945.
- 2) W. W. Carter, "Nomograms for Calculating Minimum Jamming Range for Ships", NRL Report R-2495, 1 May 1945.
- 3) K. M. Watson, "The Dependence of the Effectiveness of Clipped-Noise Jamming on the Radar Receiver Bandwidth", NRL Report R-2498, 18 July 1945.
- 4) NRL Reports R-2232, R-2295, R-2332, R-2466, and R-2467 titled respectively "Radar Cross Section of Ship Targets. II, III, IV, and V," provide measured values of σ_n and σ_f for various classes of ships.

A CHART FOR COMPUTING RADAR MINIMUM JAMMING FOR SHIPS

INTRODUCTION

The solution of the problems encountered in the simulation of ship targets by means of special radar reflectors led as a by-product to a relatively simple method for solving certain radar jamming problems. This report describes a method of determining the minimum range, from an enemy radar, at which the echo from a ship will be undetectable through jamming. Problems of this type can be divided conveniently into two general classes: (a) the problem of determining the minimum self-screening range for a ship i.e., the minimum range to which a ship carrying a jammer can approach a given radar without being detected; and (b) the problem of determining the minimum range of safe approach when the jammer is at a temporarily fixed location, not on the ship to be protected or "screened" by the jamming. The jammer may be located, for example, on another friendly craft.

The method to be described is believed to be shorter, simpler, and more general than other methods that have been used to compute minimum jamming range. It is also believed that this method would be practical for use in naval operations, and that it would be easy to teach in the schools.

As pointed out in a previous NRL report (2), the mathematical equations determining minimum jamming range cannot be solved explicitly, and in that report a set of nomograms is presented to make possible a solution without an excessively laborious calculation. Instead of using nomograms, the method to be described herein makes use of a chart and a scale, and in addition requires the numerical solution of two or three simple equations. No algebraic manipulation is involved; only an arithmetic computation. The chart, together with a movable scale graduated in logarithmic units of range, can be constructed fairly simply. Samples of these are included in this report.

BASIC THEORETICAL RELATIONS

The power density of an echo received at the radar antenna from a ship target is represented by:

$$P_n = \frac{P_r G_r \sigma_n}{(4 \pi R^2)^2} \quad P_f = \frac{P_r G_r \sigma_f}{(4 \pi R^2)^2} \left[\frac{h_r}{R} \right]^4$$

and the power density of the jamming signal received at the radar antenna is represented by the equation:

$$P_j = \frac{P_j G_j}{(4 \pi R^2)} \left[2 \sin \frac{2 \pi h_r n_j}{\lambda R} \right]^2$$

where the symbols are defined as follows:

- P_n = received echo-power density for target in the "near zone" (4)
 P_f = " " " " " " " " far zone"
 P_r = pulse power transmitted by the radar
 G_r = power gain of the radar antenna (over an "isotrope")
 h_r = height of radar antenna above water surface
 σ_n = near-zone radar cross section of the ship target (4)
 σ_f = far-zone radar cross section of the ship target
 R = range of ship (or jammer) from radar
 P_j , = received jamming-signal power density
 P_j = power transmitted by the jammer
 G_j = power gain of jamming antenna
 h_j = height of jamming antenna
 λ = radar (and jammer) wavelength

When these equations are plotted on a logarithmic graph sheet, with range as the independent variable, the two ship-echo equations become straight lines with negative slopes having numerical values of 4 and 8 for the near and far-zone cases, respectively, as shown in Figure 1. The jamming equation, beyond a certain critical range, is a straight line with slope of minus 4, as shown in Figure 2. At closer ranges, the

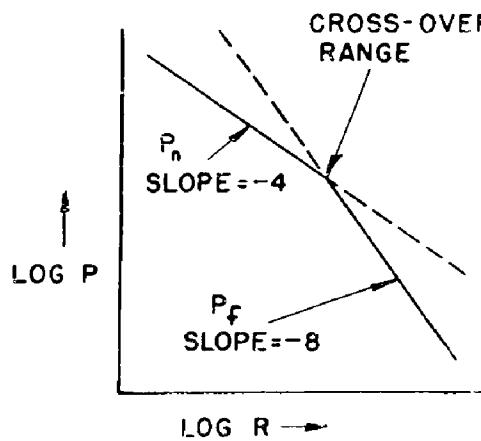


Figure 1

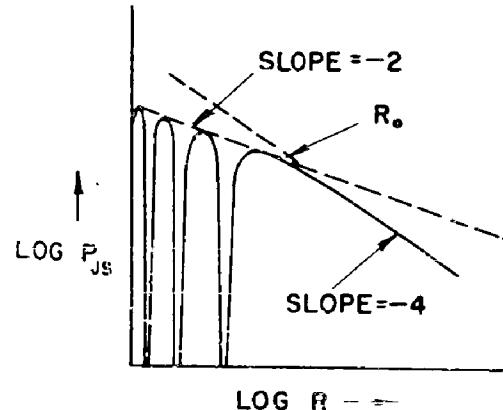


Figure 2

received-jamming-power density goes through a series of maxima and minima as would be expected because of interference between the radiation arriving via the direct path and that reflected from the sea surface.

The two ship-echo curves intersect at what may be called the "cross-over" range. The P_n curve governs at ranges closer than this, while the P_f curve is beyond the cross-over range. The region from the radar location out to the cross-over range is known as the near zone, and the region beyond the cross-over range is called the far zone.

For an ideal type of jamming signal ("pure noise"), the echo signal will be jammed whenever the jamming-signal power density (P_{js}) is equal to or greater than the echo power density (P_n , P_f). Therefore if the curves of Figures 1 and 2 are plotted on the same sheet, the point of intersection of P_{js} with either of the other curves will represent the minimum self-screening range for the particular values chosen.

For "non-ideal" types of jamming signals, the minimum jamming range may be determined by using a "corrected" figure for P_j . This corrected figure may be called the effective jamming power. It is obtained by dividing the actual jamming power by the screening ratio, whose value is determined by laboratory measurement (3).

For a complete understanding of the procedure to be described later, it is important to note that certain limiting conditions apply to the value of the minimum self-screening range:

(a) Whenever the linear portion of the jamming curve lies below the P_n curve the minimum jamming range is obviously bound to be in the far zone

(b) If the level of the jamming curve is increased indefinitely, starting at any arbitrarily low level, it will ultimately reach a value such that the intersection with the echo-power curve is on the steep portion of the jamming curve, adjacent to the null region. When this level is reached, further increase will not change the minimum jamming range appreciably. Its value becomes practically a constant independent of the jamming power. This value is, in fact, dependent only on the antenna heights and on the frequency.

The minimum range of protected approach for a given type of ship may also be determined graphically when the jamming transmitter is not located on board the ship being protected. In this case the jamming transmitter should be at some fixed arbitrary range from the radar, but not too close to a null region. First, curves similar to Figures 1 and 2 are drawn, using actual numerical values calculated from the basic equations. On the curve corresponding to Figure 2 the ordinate at the range representing the jammer's location is read. Then, on the curve corresponding to Figure 1 a horizontal line is drawn at this ordinate value. The intersection of this line with the solid portion of either the P_n or the P_f curve gives the desired minimum jamming range.

Obviously this curve-plotting procedure for determining the minimum jamming range requires excessive labor and is tedious. The need for a shorter, less laborious method of computation such as the one to be described, is evident.

THE CHART METHOD

Samples of the chart used in this method of computation are included in this report as Figures 3 and 4. Once made, the chart can be used indefinitely for the solution of specific jamming problems. Or, if sufficient use can be made of the charts to justify the expense, a "master" can be made and copies made from it by some standard reproduction process.

This chart method is actually the same as the graphical method of solution, except that by making the chart with generalized coordinates, the labor of plotting curves in the solution of specific problems is avoided. The procedure for using the chart is one which first locates the minimum-jamming-range point in terms of the generalized coordinates and then evaluates this point in actual range units of yards.

The chart can be made conveniently by using semi-log cross-section paper. The abscissas, laid off on the logarithmic divisions represent range, and the ordinates (linear divisions) represent relative power levels in decibels. The ordinates laid off in this way are of course equivalent to the logarithmic ordinates used in plotting the curves of Figures 1 and 2.

The two solid slanting lines on the chart have slopes of minus 4 and minus 8, as do the curves of Figure 1. The "slope = -4" line on the chart represents the linear portion of the jamming curve of Figure 2. As can be seen, this line is continued leftward beyond the linear portion into the "null" region. The "slope = -8" line which is representative, in a sense, of the P_f curve (Figure 1) is used only indirectly as a guide for drawing other "slope = -8" lines in the process of solving specific problems.

A movable scale which is represented on the sample charts, is quite useful in carrying out the calculations. This scale is graduated logarithmically and marked with numerical range values in this case, in yards. Although not essential, the scale saves the operation of multiplying a pair of numbers.

If the scale is provided, the vertical lines on the chart are unnecessary except for the very heavy one at the left labelled " R_o " and "range-reference axis".

If desired, however, the scale can be dispensed with and the range determination made as indicated at the end of the first example under the heading "Illustrative Examples". To make the computation in this way, the logarithmically spaced vertical lines on the chart are essential.

PROCEDURE FOR USE OF THE CHART

To make an actual computation using the chart, it is first necessary to evaluate at least two of three parameters defined as follows:

$$(a) \quad db_n = 10 (\log P_r - \log P_j) + G_r - G_j + 10 \log \sigma_n \\ - 20 \log h_r h_j f + 122.18$$

$$(b) \quad db_f = 10 (\log P_r - \log P_j) + G_r - G_j + 10 \log \sigma_f \\ - 20 \log h_r - 60 \log h_j f + 176.76$$

$$(c) \quad R_o = 1.355 h_r h_j f \times 10^{-3}$$

The symbols are defined below inasmuch as they do not have exactly the same definitions in all cases as in the equations used earlier in this report.

P_r = pulse power of radar in arbitrary units but must be same units as used for P_j

P_j = effective power of jammer, as previously defined

G_r = gain of radar antenna, in decibels (relative to an "isotropic")

G_j = gain of jamming antenna, in decibels

σ_n = near-zone radar cross section of ship being screened in, in square meters (4)

σ_f = far-zone radar cross section of same ship, in square meters (4)

h_r = height of radar antenna above water surface, in feet

h_j = height of jamming antenna, in feet

f = frequency of radar and jammer, in megacycles

R_0 = "reference range," in yards from the ship

Logarithms are to the base 10.

Minimum Jamming Range for Self-Screening Ship

Step A, Near-zone calculations

- (1) Compute db_n by substituting actual values in the foregoing expression (a).
- (2) If db_n is equal to or greater than 84, the minimum jamming range is in the far zone; consequently, proceed immediately to Step C.
- (3) If db_n is equal to or less than 69, the minimum jamming range is equal to $0.6 R_0 (=8.13 h_r h_j f \cdot 10^{-4})$. This expression represents the complete solution, and it is not necessary to proceed any further than to calculate the expression.
- (4) If db_n lies between 69 and 84, the true minimum jamming range must be determined by calculating for a "near-zone solution" and for "far-zone solution" and then taking the lesser of these two ranges as the actual minimum jamming range.

Step B, Near-zone solution

- (1) Draw a line on the chart passing through the db scale at the point representing the value computed for db_n , and parallel to the "slope = -4" line. The line thus drawn represents the echo power received from the ship at ranges in the near-zone. Note the point at which this line intersects the jamming curve. This point represents the minimum jamming range for the near-zone solution. It is now required to evaluate this point numerically.
- (2) Compute the value of R_0 . Find the point on the movable scale corresponding to this value. Place the scale on the chart, with its edge parallel to the range axis, so that the R_0 value on the scale coincides with the "range-reference" axis, the heavy vertical line near the left side of the chart.
- (3) Slide the scale up or down, keeping the R_0 value coincident with the "range-reference" axis, until the upper edge of the scale passes through the minimum-jamming-range point located in Step B (1). Read on the scale the range figure corresponding to this point. This is the near-zone solution.

Step C, Far-zone calculations

- (1) Compute db_f by substituting actual values in the foregoing expression (a).
- (2) If db_f is less than 20.5, the minimum jamming range is equal to $0.6 R_0 (=8.13 h_r h_j f \cdot 10^{-4})$. This value represents the complete solution and it is not necessary to proceed further.
- (3) If db_f is greater than 20.5, the chart must be used as described in the next step.

Step D, Far-zone solution

- (1) Draw a line on the chart passing through the db scale at the point representing the value computed for db_f , and parallel to the "slope = -8" line. The line thus drawn

represents the echo power received from the ship at ranges in the far zone. Note the point at which this line intersects the jamming curve. This point represents the far-zone solution for minimum-jamming-range. It is now required to evaluate this point numerically.

(2) Compute the value of R_o if not already computed in Step B (2). Find the point on the movable scale corresponding to this value. Place the scale on the chart, with its edge parallel to the range axis, so that the R_o value on the scale coincides with the "range-reference" axis, the heavy vertical line near the left edge of chart.

(3) Slide the scale up or down, keeping the R_o value coincident with the "range-reference" axis, until the upper edge of the scale passes through the minimum-jamming-range point located in Step D (1). Read on the scale the range figure corresponding to this point. This is the far-zone solution.

Minimum Jamming Range for Jammer at Fixed Range

In this case, the ship to be screened is not the one carrying the jammer. The jamming ship is assumed to be at a fixed range from the radar, R_j , and the ship being screened is considered to be approaching the enemy radar.

For use of the following method of calculation, two conditions, also desirable for optimum operation of the jammer, must be met:

- (1) R_j must be greater than .6 R_o , and
- (2) the jamming ship and the ship to be screened must both be on the same bearing from the radar -- that is, they must both be "in" the radar beam.

A jamming operation may be carried out under conditions which do not meet these requirements, but its chances of success are small unless it is executed in accordance with rather precise calculations based on accurate data. Relatively small errors in the data can produce very large errors in the result. On the other hand, if conditions (1) and (2) above are met, much less precision can be tolerated.

Step A: Compute db_n and db_f , and draw on the chart the corresponding "slope = -4" and "slope = -8" lines as described in the self-screening procedure.

Step B: Compute R_o . Find the point on the movable scale corresponding to this range; place the scale on the chart, with its edge parallel to the range axis, so that the R_o value on the scale coincides with the "range-reference" axis on the chart. Now find the point on the movable scale corresponding to the range R_j , the range of the jammer. Slide the scale up or down, in order to find the point on the jamming curve which corresponds with the range R_j . Through this point draw a horizontal line long enough to intersect the two sloping lines previously drawn.

Step C: The minimum jamming range is at that intersection which has the smaller range. This range is measured in the usual way with the movable scale, setting the R_o value of the scale over the "range-reference" axis.

ILLUSTRATIVE EXAMPLES

Example 1: A jammer is installed aboard the ship whose echo is to be jammed (this is the self-screening case). The pertinent characteristics of the enemy radar are known:

It is required to find the minimum jamming range, the following data being given:

$$P_i = 10^6 \text{ watts}$$

$$G_r = 38 \text{ db}$$

$$h_r = 100 \text{ feet}$$

$$f = 1500 \text{ megacycles}$$

$$P_j = 5000 \text{ watts}$$

$$G_j = 12 \text{ db}$$

$$h_j = 30 \text{ feet}$$

$$\sigma_n = 7.67 \times 10^4 \text{ meters}^2$$

$$\sigma_f = 5.04 \times 10^{14} \text{ meters}^2$$

From this data, db_n is calculated to be 87. Therefore, the minimum jamming range is in the far zone and procedure of Step C must be used.

Substituting the given data in the expression for db_f , it is found that db_f equals 53.62. Since this is greater than 20.5, the chart must be used in accordance with Step D.

Proceeding with Step D, a "slope = -8" line is drawn on the chart of Figure 3 through the 53.6 mark on the db axis. This line is seen to intersect the jammer curve at the point labelled A.

Next, R_o is computed and found to be 6100 y-rds. Placing the range scale on the chart with the 6100-yard value on the range-reference axis, and sliding it up or down until the edge of the scale passes through the point labelled A, the minimum jamming range is found to be 11,000 yards.

The minimum jamming range may be calculated without using the movable scale. To do this, note that the point A has a range coordinate of 1.8 R_o . Then multiply this value by R_o (=6100) to obtain the answer, 10,980 yards (\approx 11,000 yards).

Example 2: The jammer is at a fixed range. Assume that by use of available data it has been computed that:

$$R_o = 2000 \text{ yards}$$

$$db_n = 111$$

$$db_f = 96$$

Suppose also that $R_j = 6000$ yards. With a jammer operating at this fixed range from the radar, it is desired to determine how close a particular ship may approach safely.

The first step is to draw a "slope = -4" line through the 111-db value on the db scale and to draw a "slope = -8" line through the 96-db value, as shown on Figure 4. Then the movable scale is placed on the chart so that the 2000 yard mark (R_o) of the scale is over the "range-reference" axis. The scale is moved up or down until the 6000-yard mark (R_j) touches the jamming curve to establish the point marked B on Figure 4.

The horizontal line is drawn through the point B, and it is seen that this line intersects the sloping lines at C and D, the former being at the smaller range. The range of the point C is therefore measured with the scale, and found to be 16,000 yards. This is in the "far zone," incidentally, because C is on the "slope = -8" line.

CONSTRUCTION OF CHART AND SCALE

The general construction plan of the chart and scale may be inferred from the attached samples. The specific construction procedure is as follows:

On a sheet of four-cycle semi-logarithmic cross-section paper, oriented with the logarithmically spaced division lines running vertically, label the starting points of the successive cycles as follows, from left to right: $0.1R_o$, R_o , $10R_o$, $100R_o$; and label the end-point of the last cycle $1000R_o$. Now draw a heavy vertical line through the R_o point, and label it "range-reference axis".

On the vertical line through the $10R_o$ point, mark off decibel divisions from 0 to 160, starting at the bottom. At the 120-db level, draw a horizontal line. This is the "range axis."

Now plot the jamming curve. This is a graph of the equation shown below, plotted with the range axis and the range-reference axis as the coordinate axes. Ordinates are the decibel values and abscissas are range (R) values in terms of the reference range, R_o .

$$db = 10 \log \left[\frac{R_o}{R} \sin\left(\frac{\pi}{2} - \frac{R_o}{R}\right) \right]^2 + 120$$

For convenience in plotting, the following is a tabulation of several values of this function:

Values of R:	$0.5R_o$	$0.6R_o$	$0.7R_o$	$0.8R_o$	R_o	$2R_o$	$4R_o$	$10R_o$	$100R_o$
"db" values:	- ∞	+118.4	120.8	121.2	120	111	99.6	83.9	43.9

The movable range scale can be constructed by pasting a strip of the same four-cycle log paper onto a straight-edged piece of stiff material, such as metal, and marking it in terms of appropriate range values, for example, from 1000 to 100,000 yards.

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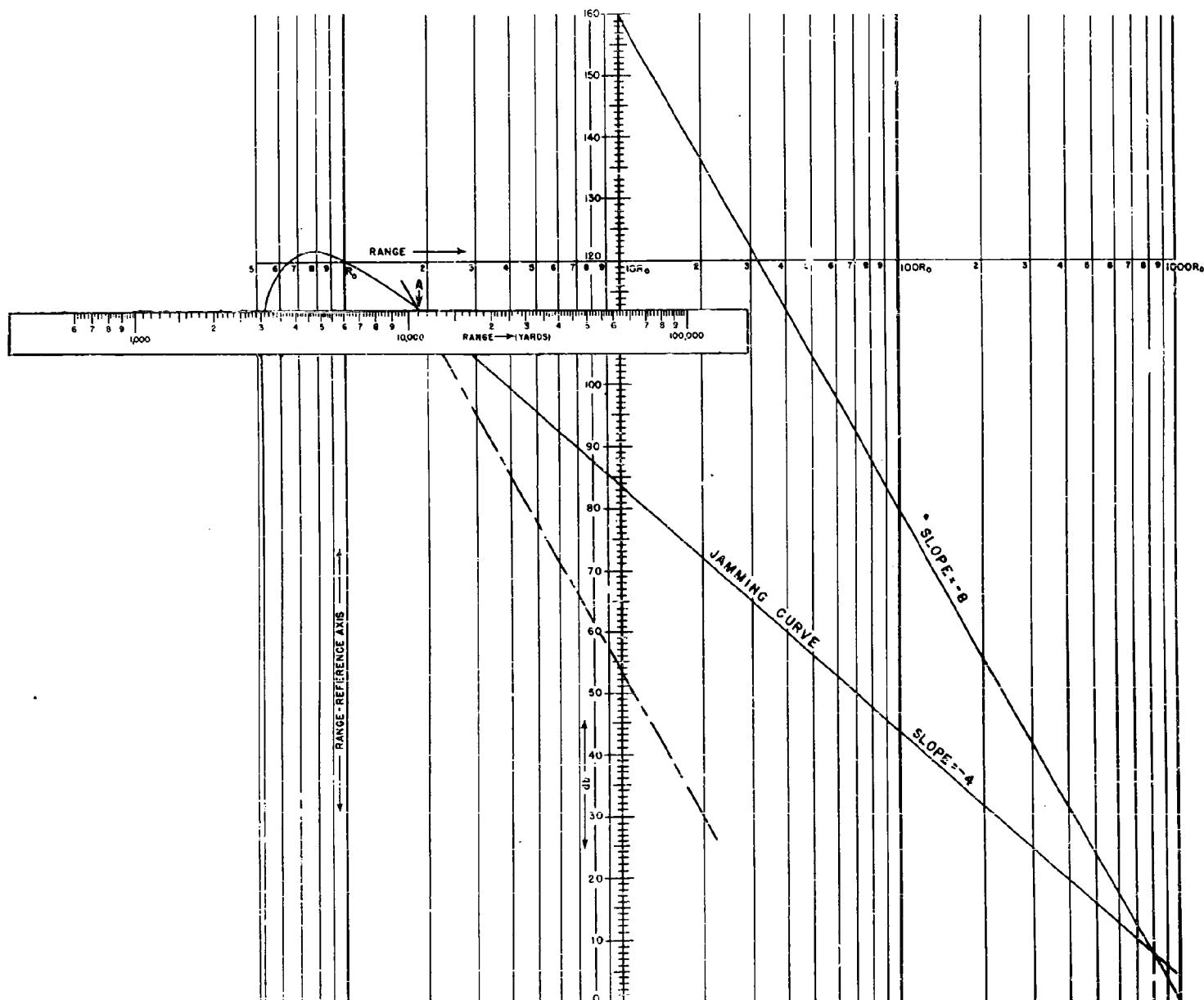


Figure 3. Jamming chart showing example 1.

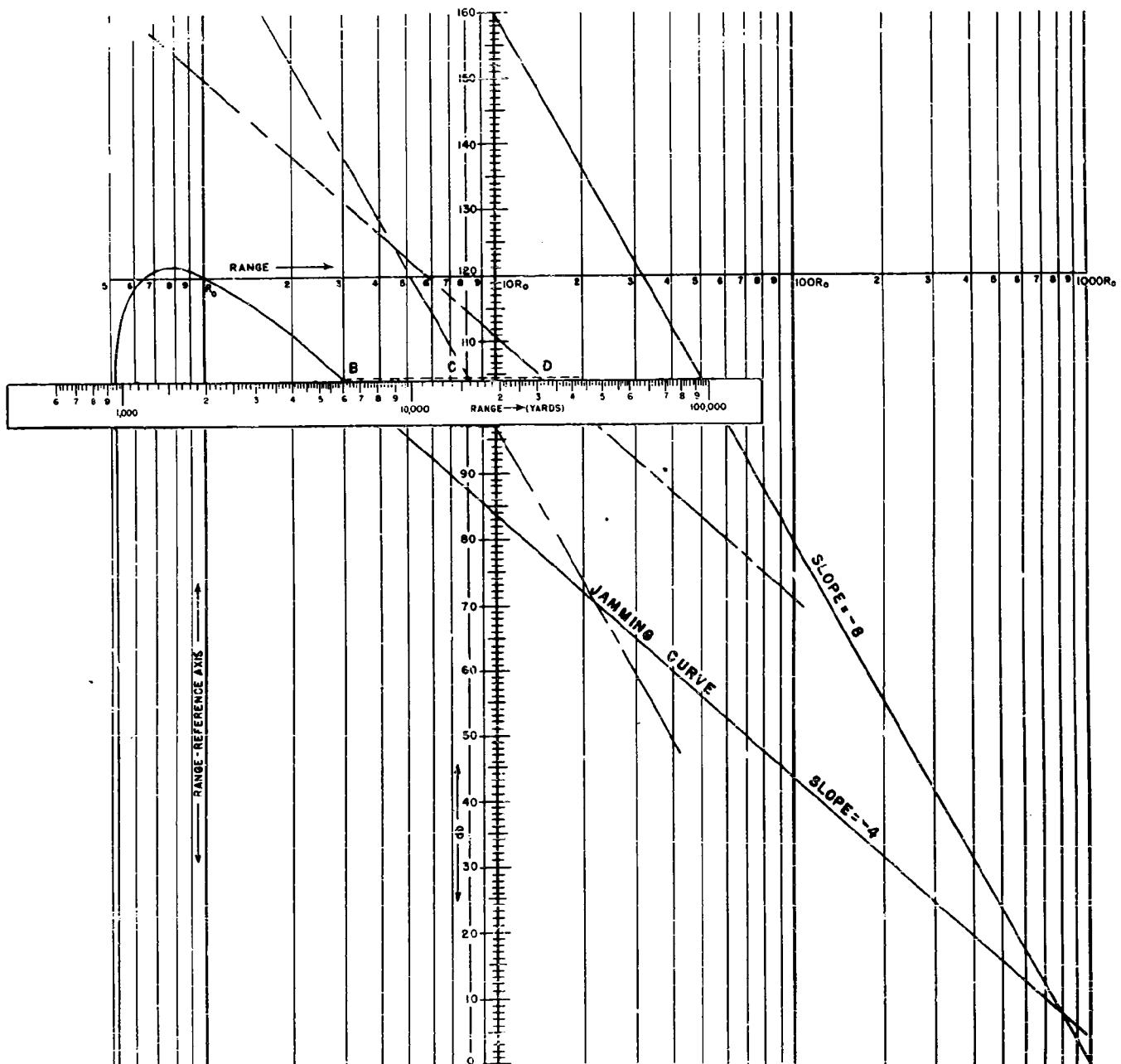


Figure 4. Jamming chart showing example 2.

Naval research laboratory. Report R-3086.
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AD - 038617

Both report can be released to
the public D.V.Trunk 9/16/99

Thank you,

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